



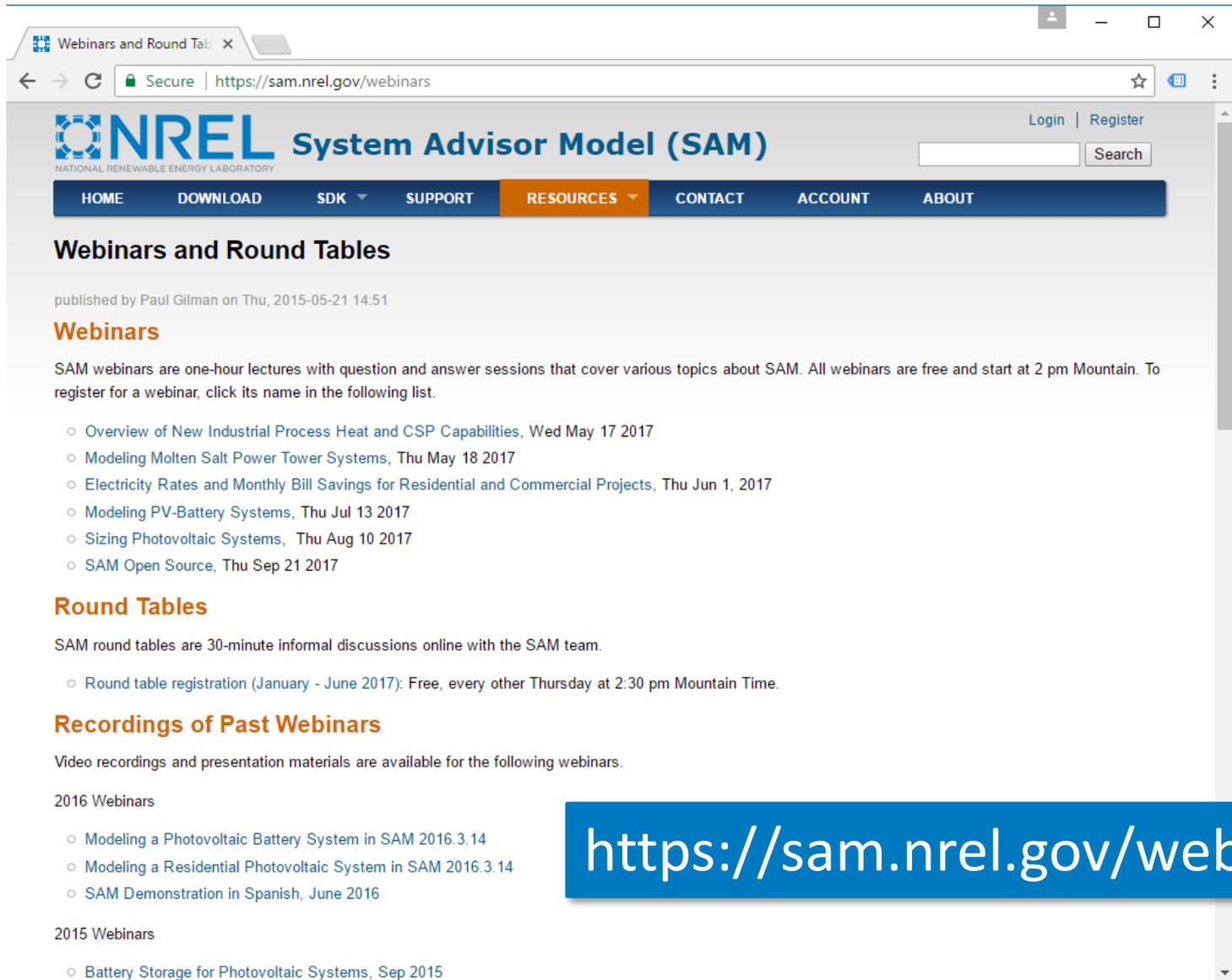
SAM Webinars 2017: Overview of New Industrial Process Heat and CSP Capabilities in SAM 2017.1.17

Paul Gilman and Ty Neises

May 17, 2017

- **Overview of New Industrial Process Heat and CSP Capabilities, May 17**
- Modeling Molten Salt Power Tower Systems, May 18
- Electricity Rates and Monthly Bill Savings for Residential and Commercial Projects, June 1
- Modeling PV-Battery Systems, July 13
- Sizing Photovoltaic Systems, August 10
- SAM Open Source, September 21

Registration Links and Webinar Recordings



The screenshot shows a web browser window displaying the NREL System Advisor Model (SAM) website. The page title is "Webinars and Round Tables". The URL in the address bar is <https://sam.nrel.gov/webinars>. The page features a navigation menu with links for HOME, DOWNLOAD, SDK, SUPPORT, RESOURCES, CONTACT, ACCOUNT, and ABOUT. The main content area is titled "Webinars and Round Tables" and includes a sub-section for "Webinars" with a list of upcoming sessions. Below this is a section for "Round Tables" and a section for "Recordings of Past Webinars" with a list of past sessions. A large blue box at the bottom right of the page contains the URL <https://sam.nrel.gov/webinars>.

Webinars and Round Tables

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Webinars

SAM webinars are one-hour lectures with question and answer sessions that cover various topics about SAM. All webinars are free and start at 2 pm Mountain. To register for a webinar, click its name in the following list.

- Overview of New Industrial Process Heat and CSP Capabilities, Wed May 17 2017
- Modeling Molten Salt Power Tower Systems, Thu May 18 2017
- Electricity Rates and Monthly Bill Savings for Residential and Commercial Projects, Thu Jun 1, 2017
- Modeling PV-Battery Systems, Thu Jul 13 2017
- Sizing Photovoltaic Systems, Thu Aug 10 2017
- SAM Open Source, Thu Sep 21 2017

Round Tables

SAM round tables are 30-minute informal discussions online with the SAM team.

- Round table registration (January - June 2017): Free, every other Thursday at 2:30 pm Mountain Time.

Recordings of Past Webinars

Video recordings and presentation materials are available for the following webinars.

2016 Webinars

- Modeling a Photovoltaic Battery System in SAM 2016.3.14
- Modeling a Residential Photovoltaic System in SAM 2016.3.14
- SAM Demonstration in Spanish, June 2016

2015 Webinars

- Battery Storage for Photovoltaic Systems, Sep 2015

<https://sam.nrel.gov/webinars>

Outline

- What's new for CSP in SAM 2017.1.17
- Industrial process heat (IPH) applications
- Levelized cost of heat
- Parabolic trough IPH model
- Linear direct steam IPH model
- Q&A

- CSP Generic model uses a different set of regression equations for thermal losses, power cycle conversion efficiency, and parasitic consumption
 - You will need to calculate different coefficients than for the CSP Generic model in older versions of SAM
- Power Tower model improvements to dispatch and solar field optimization algorithms
 - Tomorrow's webinar will discuss in detail
- New solar industrial process heat models

A note on terminology

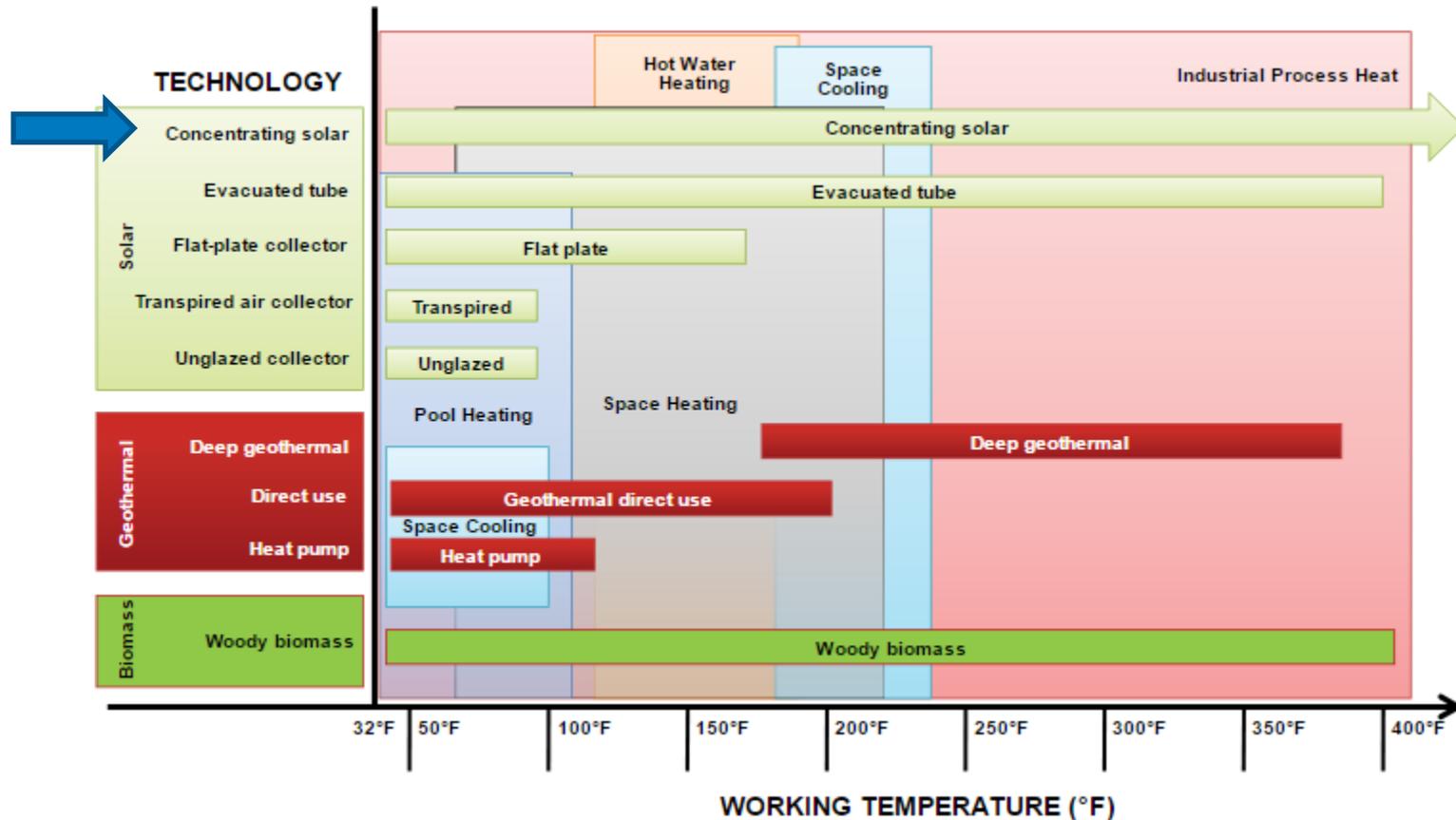
- Concentrating solar power (CSP)
 - A field of concentrating solar collectors coupled to a power cycle for electricity generation. Typically high-temperature, large-scale systems.
- Solar industrial process heat (SIPH, or IPH for short)
 - Concentrating solar collectors used to provide direct steam or heat for a thermal process.
 - Typically replaces or supplements a fossil-fired boiler

CSP = Electricity Generation



IPH = Process Heat

IPH applications for trough and linear Fresnel collectors



HTF of choice: Direct Steam Mineral Oil Synthetic Oil

Source: EPA Renewable Heating and Cooling website, Kurup (2015) paper on IPH for Southwest U.S.

Overview of market status for IPH prepared by NREL for DOE

- Applications
- Collector costs
- Examples of systems
- References to other sources of information

www.nrel.gov/docs/fy16osti/64709.pdf



Initial Investigation into the Potential of CSP Industrial Process Heat for the Southwest United States

Parthiv Kurup and Craig Turchi
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy
Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-6A20-64709
November 2015

Contract No. DE-AC36-08GO28308

Levelized cost of heat (LCOH)

$$LCOH = \frac{(Total\ installed\ project\ cost) * (FCR) + (Annual\ O\&M)}{Annual\ thermal\ generation}$$

- Accounts for installation and operating costs, project financial requirements, and thermal output of collectors
- Compare cost per kWh of solar-thermal energy to cost per MMBtu of natural gas
- Not a cash-flow method
- Requires calculating the fixed charge rate, which is the revenue per amount of investment required to cover the investment cost
 - Described in SAM's "LCOE Calculator" Help topic

IPH models in SAM were adapted from CSP models

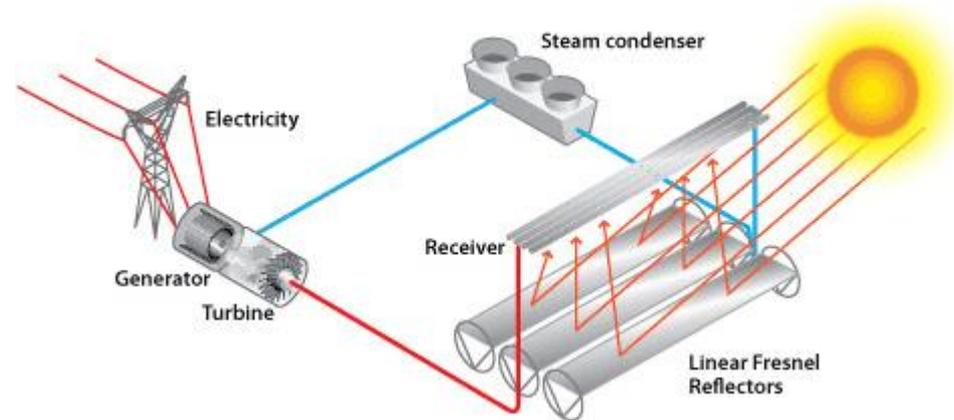
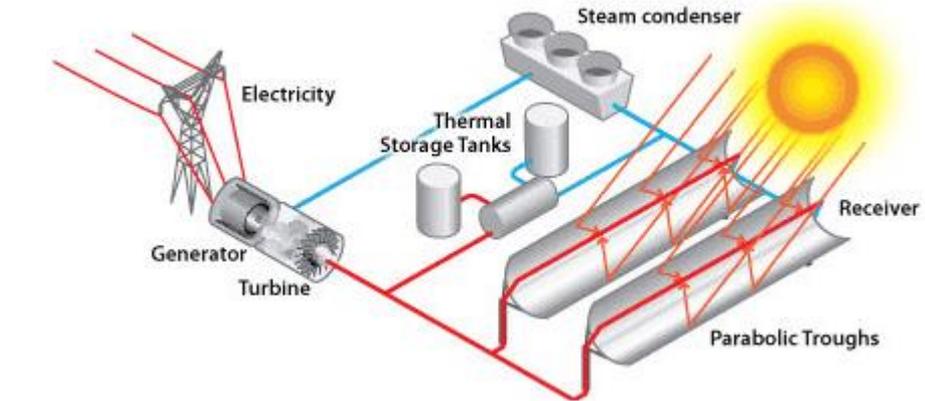
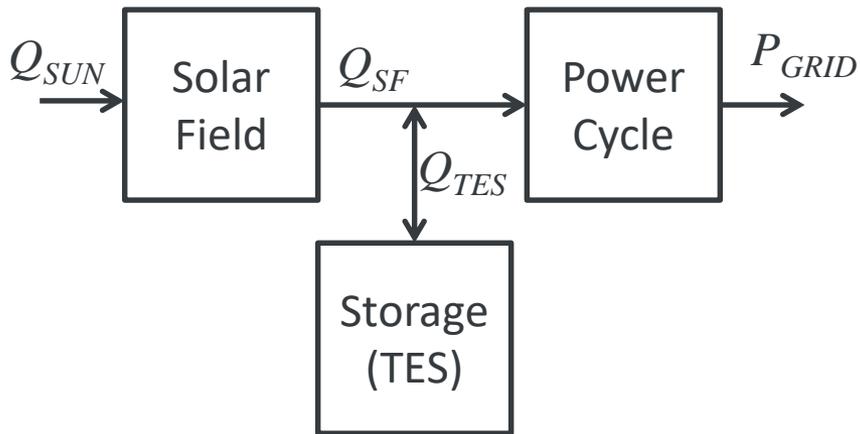
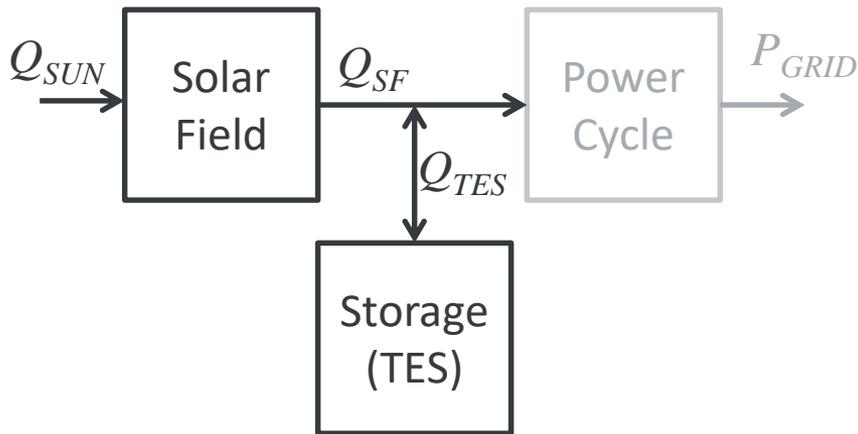


Image source DOE EERE

Before SAM 2017.1.17, model IPH by ignoring power cycle



Power cycle capacity equal to solar field capacity

Boiler operating pressure to saturated steam pressure at solar field outlet temperature

Auxiliary heater outlet temperature to solar field outlet temperature

Power cycle startup time and power to zero, startup temperature to field inlet temperature

Max oversize operation to 2 times design, and minimum operation to 0.02

Cost and financial models not designed for thermal application

Technique described in 2015 milestone report to DOE, available on SAM website:
“Geothermal Risk Reduction via Geothermal/Solar Hybrid Power Plants”

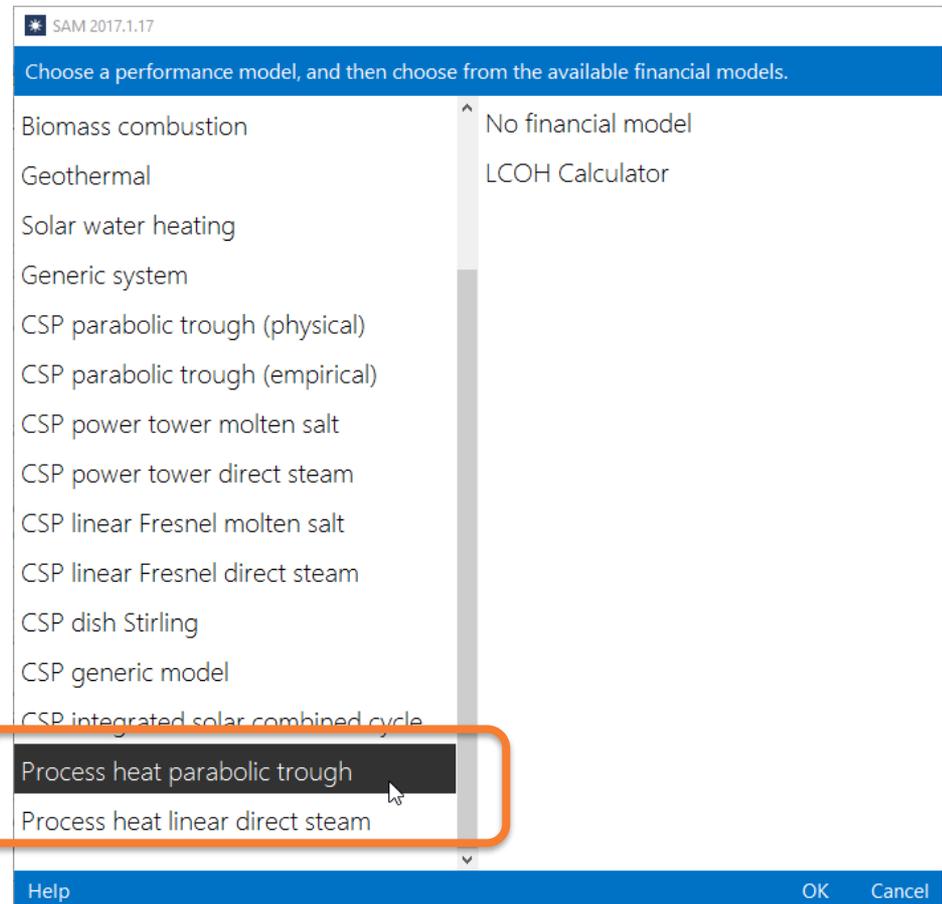
- IPH parabolic trough
 - Physical model of trough collectors and receivers
 - Pressurized water, oil, or salt HTF
- IPH linear direct steam
 - General optical model of field
 - Most of receiver at a single temperature
 - Saturated steam with user-specified steam quality
 - Two-phase steam at field outlet, completely condensed at inlet

If you are learning about concentrating solar for IPH...

- The IPH trough model may be a better starting point because it characterizes the system performance more completely
 - Physical models of collector and receiver
 - Calculate pressure drops
 - Flow rate limitations
- IPH direct steam model requires more data as input
 - Optical efficiency tables or IAM coefficients
 - Pressure drops

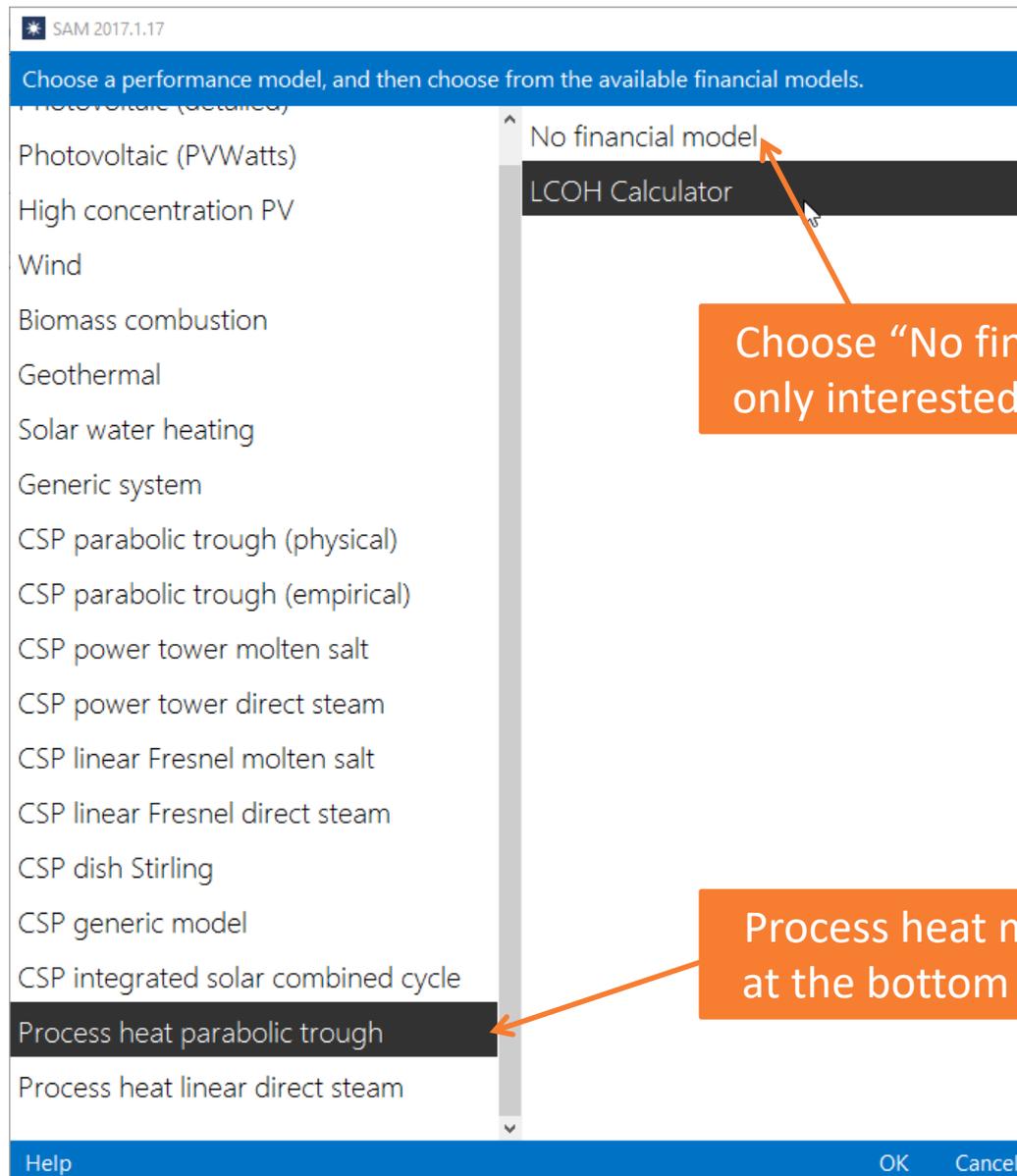
IPH models in SAM 2017.1.17

- Physical trough and linear direct steam models with power cycle removed
- Basic financial model uses fixed-charge-rate method to calculate “levelized cost of heat”
- Thermal storage not yet implemented, coming soon! (for IPH trough with oil or salt HTF only)



IPH Parabolic Trough

Choose performance model and financial model



Choose "No financial model" if you are only interested in system performance.

Process heat models are at the bottom of the list.

Input pages provide access to input parameters

The screenshot shows the SAM 2017.1.17 software interface. The top menu bar includes 'File', '+ Add', 'untitled', and 'Help'. The left sidebar contains vertical tabs for 'Location and Resource', 'System Design', 'Solar Field', 'Collectors (SCAs)', 'Receivers (HCEs)', and 'Financial Parameters'. The main window displays the 'Download a weather file from the NREL NSRDB' section, which includes a 'Download...' button and a 'Choose a weather file from the solar resource library' section. The library section features a search box and a table of weather files. Below the table are input fields for City, State, Country, Time zone, Elevation, Latitude, Longitude, and Station ID. A 'Data file' field shows the path 'C:\SAM\2017.1.17\solar_resource\USA CA Imperial (TMY3).csv'. The 'Annual Weather Data Summary' section displays 'Global horizontal' as 5.77 kWh/m²/day, 'Average temperature' as 23.4 °C, and 'Average wind speed' as 3.3 m/s. A 'Tools' section on the right includes buttons for 'View data...', 'Refresh library', 'Folder settings...', and 'Open library folder...'. At the bottom, a 'Simulate' button is highlighted, with a sub-menu showing 'Parametrics', 'Stochastic', 'P50 / P90', and 'Macros'. Annotations with orange boxes and arrows point to the 'Help' button, the 'Financial Parameters' tab, the 'Simulate' button, and the 'Simulate' sub-menu.

Opens the Help system.

Click vertical tabs to display input pages.

Click "Simulate" to run a simulation.

Displays results without running a simulation.

Name	Station ID	Latitude	Longitude	Time zone	Elevation
USA CA Fresno (TMY2)	93193	36.7667	-119.717	-8	100
USA CA Fresno (TMY3)	93193	36.783	-119.717	-8	102
USA CA Fresno (TMY3)	93193	33.867	-117.983	-8	29
USA CA Fresno (TMY3)	93193	37.667	-122.117	-8	14
USA CA Imperial (TMY3)	747185	32.833	-115.583	-8	-17
USA CA Imperial (TMY3)	747185	33.017	-118.333	-8	21

Weather file provides information about solar resource and ambient conditions

The screenshot displays the SAM 2017.1.17 software interface. The left sidebar contains navigation options: Location and Resource, Solar Field, Power Block, Thermal Storage, System Costs, Lifetime, Financial Parameters, Time of Delivery Factors, Incentives, and Depreciation. The main window is titled 'untitled' and has a 'File' menu and 'Add' button. The 'Download a weather file from the NREL NSRDB' section features a 'Download...' button and a text box explaining that clicking 'Download' adds the file to the solar resource library. An orange callout box points to this button with the text 'Download weather data from the NSRDB.' Below this is a table of weather files from the solar resource library. The table has columns for Name, Station ID, Latitude, Longitude, Time zone, and Elevation. The 'USA CA Daggett (TMY2)' entry is highlighted. An orange callout box points to the '23161' Station ID with the text 'Use weather file stored on computer.' Below the table are input fields for City (Daggett), State (CA), Country (USA), and Data file (C:\SAM\2017.1.17). The 'Time zone' is set to GMT -8, and 'Latitude' is 34.8667°N. The 'Tools' section includes buttons for 'View data...', 'Refresh library', 'Folder settings...', and 'Open library folder...'. The 'Annual Weather Data Summary' section shows: Global horizontal (5.86 kWh/m²/day), Direct normal (beam) (7.65 kWh/m²/day), Diffuse horizontal (1.34 kWh/m²/day), Average temperature (19.8 °C), and Average wind speed (4.9 m/s). A 'Visit SAM weather data website' link is provided. At the bottom, the 'Use a specific weather file on disk' section has a checkbox and a 'Browse...' button. The bottom left of the interface has 'Simulate >' and 'Parametrics Stochastic P50 / P90 Macros'.

Name	Station ID	Latitude	Longitude	Time zone	Elevation
USA CA Chino Airport (TMY3)	722899	33.967	-117.633	-8	198
USA CA Chula Vista Brown Field Naas (TMY3)	722904	32.583	-116.983	-8	159
USA CA Concord Concord-buchanan Fiel (TMY3)	724936	38	-122.05	-8	7
USA CA Crescent City Faa Ai (TMY3)	725946	41.783	-124.233	-8	17
USA CA Daggett (TMY2)	23161	34.8667	-116.783	-8	588
USA CA Daggett Bartow-daggett Ap (TMY3)	723815	34.85	-116.8	-8	586

System Design page provides access to main design parameters

The screenshot displays the SAM 2017.1.17 software interface. The left sidebar shows the navigation menu with 'System Design' selected. The main window is divided into two sections: 'Design Point Parameters' and 'System Summary'. The 'Design Point Parameters' section includes input fields for Design point DNI (950 W/m²), Target solar multiple (1), Target receiver thermal power (5.19 MWt), Loop inlet HTF temperature (90 °C), and Loop outlet HTF temperature (150 °C). The 'System Summary' section shows calculated values: Actual number of loops (3), Total aperture reflective area (7,872.0 m²), Actual solar multiple (1.00), and Actual field thermal output (5.19 MWt). Two orange callout boxes provide context: one points to the Design point DNI field, stating it determines field size assuming summer solstice sun position; the other points to the Target solar multiple field, stating it is for systems with storage (available soon). A 'Choose Number of Loops' button is visible next to the HTF temperature fields. The 'System Availability and Curtailment' section shows a constant loss of 4.0% and no hourly or custom period losses.

Design point DNI determines size of field assuming summer solstice sun position.

Target solar multiple for systems with storage (available soon).

Parameter	Value	Units
Design point DNI	950	W/m ²
Target solar multiple	1	
Target receiver thermal power	5.19	MWt
Loop inlet HTF temperature	90	°C
Loop outlet HTF temperature	150	°C
Actual number of loops	3	
Total aperture reflective area	7,872.0	m ²
Actual solar multiple	1.00	
Actual field thermal output	5.19	MWt

Loop inlet and outlet temperatures should be within HTF operating ranges

The screenshot displays the SAM 2017.1.17 software interface. The left sidebar shows navigation options: Location and Resource, System Design, Solar Field, Collectors (SCAs), Receivers (HCEs), and Financial Parameters. The main window is titled "Design Point Parameters" and is divided into several sections:

- Design Point Parameters:**
 - Solar Field:** Design point DNI (950 W/m²), Target solar multiple (1), Target receiver thermal power (5.19 MWt), Loop inlet HTF temperature (90 °C), Loop outlet HTF temperature (150 °C).
 - Heat Sink:** Heat sink power (5.19 MWt), Pumping power for HTF through heat sink (0.55 kW/kg/s), and a "Choose Number of Loops" button.
 - System Availability and Curtailment:** Curtailment and availability losses reduce the system output to represent system outages or other events. Includes an "Edit losses..." button and summary: Constant loss: 4.0 %, Hourly losses: None, Custom periods: None.
- System Summary:** Actual number of loops (3), Total aperture reflective area (7,872.0 m²), Actual solar multiple (1.00), Actual field thermal output (5.19 MWt).
- Heat Transfer Fluid:** Field HTF fluid (Pressurized Water), User-defined HTF fluid (button), Field HTF min operating temp (10 °C), Field HTF max operating temp (220 °C), Freeze protection temp (10 °C), Min single loop flow rate (1 kg/s), Max single loop flow rate (12 kg/s).

An orange callout box on the left states: "HTF properties are on the Solar Field input page." An orange arrow points from the "Loop inlet HTF temperature" and "Loop outlet HTF temperature" fields in the Design Point Parameters section to the "Field HTF min operating temp" and "Field HTF max operating temp" fields in the Heat Transfer Fluid section.

At the bottom, an orange callout box states: "SAM allows the system to operate outside of these HTF operating temperatures, so you should check temperatures in results to avoid exceeding physical limits."

At the bottom left, there are buttons for "Simulate >", "Parametrics", "Stochastic", "P50 / P90", and "Macros".

Heat sink power is the capacity or thermal load of the system in thermal megawatts

The screenshot shows the SAM 2017.1.17 software interface. The left sidebar contains a navigation menu with the following items: Location and Resource, System Design (highlighted), Solar Field, Collectors (SCAs), Receivers (HCFs), and Fin. The main window is titled "IPH Trough, LCOH Calculator" and contains two main sections: "Design Point Parameters" and "System Summary".

Design Point Parameters

-Solar Field-		-Heat Sink-	
Design point DNI	950 W/m ²	Heat sink power	5.19 MWt
Target solar multiple	1	Pumping power for HTF through heat sink	0.55 kW/kg/s
Target receiver thermal power	5.19 MWt	<input type="button" value="Choose Number of Loops"/>	
Loop inlet HTF temperature	90 °C		
Loop outlet HTF temperature	150 °C		

System Summary

Actual number of loops	3	Actual solar multiple	1.00
Total aperture reflective area	7,872.0 m ²	Actual field thermal output	5.19 MWt

An orange callout box with white text is positioned over the "Choose Number of Loops" button, with an arrow pointing to it. The text reads: "Either type a value for the heat sink power, or click 'Choose Number of Loops' to calculate the power based on a desired number of loops."

Another orange callout box with white text is positioned below the "System Summary" section. The text reads: "SAM calculates the system summary parameters based on the other values you enter."

At the bottom of the interface, there is a blue bar with the "Simulate" button and a bar chart icon. Below this bar are the labels "Parametrics", "Stochastic", "P50 / P90", and "Macros".

The “constant loss” of 4% is equivalent to a 96% annual availability factor and may not be appropriate for IPH

The screenshot shows the SAM 2017.1.17 software interface for an IPH Trough, LCOH Calculator. The left sidebar contains navigation options: Location and Resource, System Design (selected), Solar Field, Collectors (SCAs), Receivers (HCEs), and Financial Parameters. The main window is titled "Design Point Parameters" and is divided into three sections:

- Solar Field-**: Design point DNI (950 W/m²), Target solar multiple (1), Target receiver thermal power (5.19 MWt), Loop inlet HTF temperature (90 °C), and Loop outlet HTF temperature (150 °C).
- Heat Sink-**: Heat sink power (5.19 MWt) and Pumping power for HTF through heat sink (0.55 kW/kg/s). A "Choose Number of Loops" button is present.
- System Availability and Curtailment-**: A note states "Curtailment and availability losses reduce the system output to represent system outages or other events." An "Edit losses..." button is highlighted with an orange arrow pointing to a tooltip that reads: "Constant loss: 4.0 %", "Hourly losses: None", and "Custom periods: None".

At the bottom of the main window, there are two rows of results:

- Total aperture reflective area: 3,872.0 m²
- Actual solar multiple: 1.00
- Actual field thermal output: 5.19 MWt

An orange callout box with white text says: "Click 'Edit losses' to change the default value." The bottom of the interface includes a "Simulate" button and a menu with "Parametrics", "Stochastic", "P50 / P90", and "Macros".

Solar Field inputs are the same as physical trough model, except for piping between solar field and heat sink

System Design Parameters

Design Point DNI	950 W/m ²	Loop inlet HTF temperature	90.0 °C
Target solar multiple	1.00	Loop outlet HTF temperature	150.0 °C
Target receiver thermal power	3.46 MWt		

Solar Field Design Point

Single loop aperture	2,624.0 m ²	Actual number of loops	2
Loop optical efficiency	0.7213	Total aperture reflective area	5,248.0 m ²
Total loop conversion efficiency	0.6937	Actual solar multiple	1.00
Total required aperture, SM=1	5,248.0 m ²	Actual field thermal output	3.46 MWt
Required number of loops, SM=1	2.00		

Solar Field Parameters

Row spacing	15 m
Stow angle	170 deg
Deploy angle	10 deg
Header pipe roughness	4.57e-005 m
Pump efficiency	0.85
Heat loss coefficient	0.45 W/m ² -K
Design power per SCA	125.0 W/sca
Total tracking power	1,000.0 W
Number of field subsections	1
Model piping through heat sink?	<input type="checkbox"/>
Length of piping through heat sink	50.0 m

Heat Transfer Fluid

Field HTF fluid	Pressurized Water
User-defined HTF fluid	Edit...
Field HTF min operating temp	10 °C
Field HTF max operating temp	220 °C
Freeze protection temp	10 °C
Min single loop flow rate	1 kg/s
Header design min flow velocity	2 m/s

Collector Orientation

Collector	
Collector	

Mirror Washing

Water usage per wash	0.7 L/m ² ,aper.
Washes per year	12

Plant Heat Capacity

Hot piping thermal inertia	0.2 kWh/K-MWt
Cold piping thermal inertia	0.2 kWh/K-MWt
Field loop piping thermal inertia	4.5 Wht/K-m

IPH model allows one subsection.

Includes only first header in subsection unless you check this box.

These parameters affect heat loss, thermal inertia and capacity, and pumping power.

Unlike CSP model, IPH model only defocuses field when HTF flow rate exceeds maximum flow limit

System Design Parameters

Design Point DNI	950 W/m ²	Loop inlet HTF temperature	90.0 °C
Target solar multiple	1.00	Loop outlet HTF temperature	150.0 °C
Target receiver thermal power	3.46 MWt		

Solar Field Design Point

Single loop aperture	2,624.0 m ²	Actual number of loops	2
Loop optical efficiency	0.7213	Total aperture reflective area	5,248.0 m ²
Total loop conversion efficiency	0.6937	Actual solar multiple	1.00
Total required aperture, SM=1	5,248.0 m ²	Actual field thermal output	3.46 MWt
Required number of loops, SM=1	2.00		

Solar Field Parameters

Row spacing	15 m
Stow angle	170 deg

Heat Transfer Fluid

Field HTF fluid	Pressurized Water
User-defined HTF fluid	Edit...
Field HTF min operating temp	10 °C
Field HTF max operating temp	220 °C
Freeze protection temp	10 °C
Min single loop flow rate	1 kg/s
Max single loop flow rate	12 kg/s
Min field flow velocity	0.228212 m/s
Max field flow velocity	2.87905 m/s
Header design min flow velocity	2 m/s
Header design max flow velocity	3 m/s

Collector Orientation

Collector tilt	0 deg	Tilt: horizontal=0, vertical=90
Collector azimuth	0 deg	Azimuth: equator=0, west=90, east=-90

Mirror Washing

Water usage per wash	0.7 L/m ² , aper.
Washes per year	12

Plant Heat Capacity

Hot piping thermal inertia	0.2 kWh/K-MWt
Cold piping thermal inertia	0.2 kWh/K-MWt
Field loop piping thermal inertia	4.5 Wht/K-m

Flow rate limits determine when field defocuses collectors.

Collectors are the same as the CSP physical trough model

The screenshot displays the SAM 2017.1.17 software interface. The main window is titled "Collector Library" and contains a table of collector types. The table has columns for Name, Reflective aper..., Aperture width..., Length of colle..., and Number of mo... The following table represents the data from the screenshot:

Name	Reflective aper...	Aperture width...	Length of colle...	Number of mo...
AlbiosaTrough AT150	817.5	5.774	150	12
Siemens SunField 6	545	5.776	95.2	8
SkyFuel SkyTrough (with 80-mm OD receiver)	656	6	115	8
FLABEG Ultimate Trough RP6 (with 89-mm OD receiver for oil ...	1720			

Below the table, there is a "Collector types in loop configuration" field showing "Cold - 1 - 1 - 1 - Hot". An "Apply Values from Library" button is visible. The "Optical Parameters" section includes fields for Incidence angle modifier coefficients, Tracking error (0.988), General optical error (1), Geometry effects (0.952), Mirror reflectance (0.93), and Dirt on mirror (0.97). The "Optical Calculations" section includes Length of single module (14.375 m), IAM at summer solstice (1.00176), End loss at summer solstice (0.999614), and Optical efficiency at design (0.848494).

Annotations in orange boxes provide instructions:

- "Choose a collector from the library..." points to the collector table.
- "Diagram of loop showing position of collector types as defined at bottom of Solar Field page." points to the loop configuration field.
- "...and then apply parameters from library to collector type." points to the "Apply Values from Library" button.
- "If the field contains different types of collectors, configure them here." points to the "Collector Type 2", "Collector Type 3", and "Collector Type 4" options at the bottom.

Use the loop configuration to set number of collectors per loop, assign collector and receiver types, and defocus order

Loop configuration is at bottom of Solar Field page.
You may need to scroll down the window to see it.

Single Loop Configuration

The specification below is on page 10 of the Solar Field Configuration Manual.

Usage tip: To configure the loop, choose whether to edit SCAs, HCEs or defocus order. Select multiple items. Assign types to selected items by pressing keys 1-4.

Number of SCA/HCE assemblies per loop: Edit SCAs Edit HCEs Edit Defocus Order

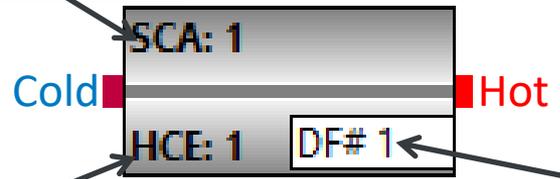
1. Type number of collector assemblies per loop.

2. Click a collector to select it.

3. Choose an item to edit.

4. Type a number on your keyboard to change a number.

Collector type number



Receiver type number

Defocus order is not applicable for IPH model.

Receivers are the same as the CSP physical trough model

SAM 2017.1.17

File Add untitled Help

IPH Trough, LCOH Calculator

Location and Resource

System Design

Solar Field

Collectors (SCAs)

Receivers (HCEs)

Financial Parameters

Receiver Library

Search for: Name

Name	Absorber tube ...	Absorber tube ...	Glass envelo...	Glass envelo...
Solel UVAC 3	0.066	0.07	0.115	0.121
Siemens UVAC 2010	0.066	0.07	0.109	0.115
Schott PTR80	0.076	0.08	0.115	0.12
Royal Tech CSP RTUJVR 2014 (Manufacturer Specifications)	0.066	0.07	0.119	0.125

Receiver types in loop configuration: Cold - 1 - 1 - 1 - 1 - Hot

Receiver Type 1

Receiver name from library: Schott PTR80 Apply Values from Library

Receiver Geometry

Absorber tube inner diameter: m

Absorber tube outer diameter: m

Glass envelope inner diameter: m

Glass envelope outer diameter: m

Absorber flow plug diameter: m

Internal surface roughness:

Absorber flow pattern:

Absorber material type:

Parameters and Variations

	Variation 1	Variation 2	Variation 3	Variation 4*
Variant weighting fraction*	<input type="text" value="0.985"/>	<input type="text" value="0.01"/>	<input type="text" value="0.005"/>	<input type="text" value="0"/>
Absorber Parameters:				
Absorber absorptance	<input type="text" value="0.963"/>	<input type="text" value="0.963"/>	<input type="text" value="0.8"/>	<input type="text" value="0"/>
Absorber emittance	<input type="text" value="Table..."/>	<input type="text" value="0.65"/>	<input type="text" value="0.65"/>	<input type="text" value="0"/>
Envelope Parameters:				
Envelope absorptance	<input type="text" value="0.02"/>	<input type="text" value="0.2"/>	<input type="text" value="0"/>	<input type="text" value="0"/>
Envelope emittance	<input type="text" value="0.86"/>	<input type="text" value="0.86"/>	<input type="text" value="1"/>	<input type="text" value="0"/>
Envelope transmittance	<input type="text" value="0.964"/>	<input type="text" value="0.964"/>	<input type="text" value="1"/>	<input type="text" value="0"/>
	<input type="checkbox"/> Broken Glass	<input type="checkbox"/> Broken Glass	<input checked="" type="checkbox"/> Broken Glass	<input type="checkbox"/> Broken Glass
Gas Parameters:				
Annulus gas type	<input type="text" value="Air"/>	<input type="text" value="Air"/>	<input type="text" value="Air"/>	<input type="text" value="Air"/>
Annulus pressure (torr)	<input type="text" value="0.0001"/>	<input type="text" value="750"/>	<input type="text" value="750"/>	<input type="text" value="0"/>

Simulate >

Parametrics Stochastic

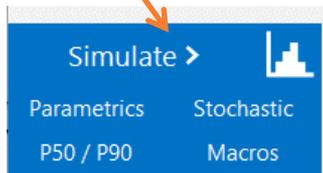
P50 / P90 Macros

Either provide a fixed charge rate (FCR), or use the calculator and provide financial parameters

The screenshot shows the SAM 2017.1.17 interface with the 'IPH Trough, LCOH Calculator' selected. The 'Levelized Cost Of Heat' section includes a text box explaining the model and an 'Electricity Rate' input field set to 0.060 \$/kWh. The 'LCOE Calculator' section is active, showing 'Capital and Operating Costs' with inputs for system capacity (3,458.61 kW), capital cost (2,755,000.00), fixed operating cost (41,600.00), and variable operating cost (0.0010 \$/kWh). The 'Financial Assumptions' section has 'Calculate fixed charge rate' selected, with a 'Fixed charge rate (FCR)' output field showing 0.108. An orange callout box with an arrow pointing to the FCR field contains the text: 'FCR is either the value you enter, or the value SAM calculates from the financial parameters you enter.'

Run a simulation to generate results

Click Simulate



When you run a simulation, SAM performs a set of calculations for each hour of the year to calculate the thermal energy produced by the solar field.

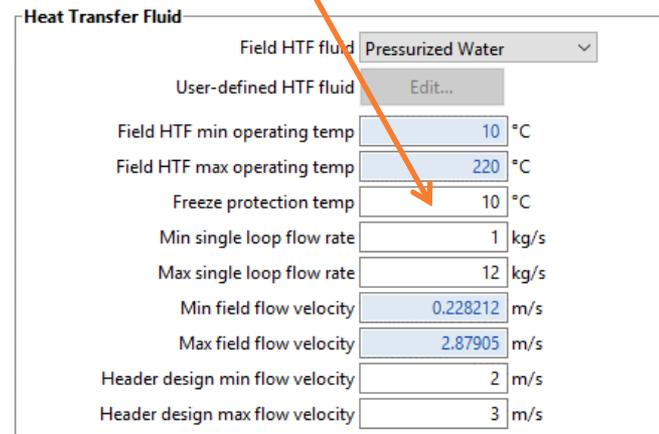
If you included the LCOH calculator when you created the case, it also calculates the LCOH using the sum of the hourly energy values to represent the total annual thermal energy produced by the field.

The Metrics table displays a summary of results

- Annual energy and annual field energy are the same when freeze protection energy is zero
- Electricity load is for pumping and tracking power

Metric	Value
Annual energy (year 1)	7,389,923 kWh-t
Annual field energy (year 1)	7,389,923 kWh-t
Annual thermal freeze protection (year 1)	0 kWh-t
Annual electricity load (year 1)	25,762 kWh-e
Levelized cost of heat	3.33 ¢/kWh-t

Increase freeze protection temperature on Solar Field page to add freeze protection energy.



Heat Transfer Fluid

Field HTF fluid: Pressurized Water

User-defined HTF fluid: Edit...

Field HTF min operating temp: 10 °C

Field HTF max operating temp: 220 °C

Freeze protection temp: 10 °C

Min single loop flow rate: 1 kg/s

Max single loop flow rate: 12 kg/s

Min field flow velocity: 0.228212 m/s

Max field flow velocity: 2.87905 m/s

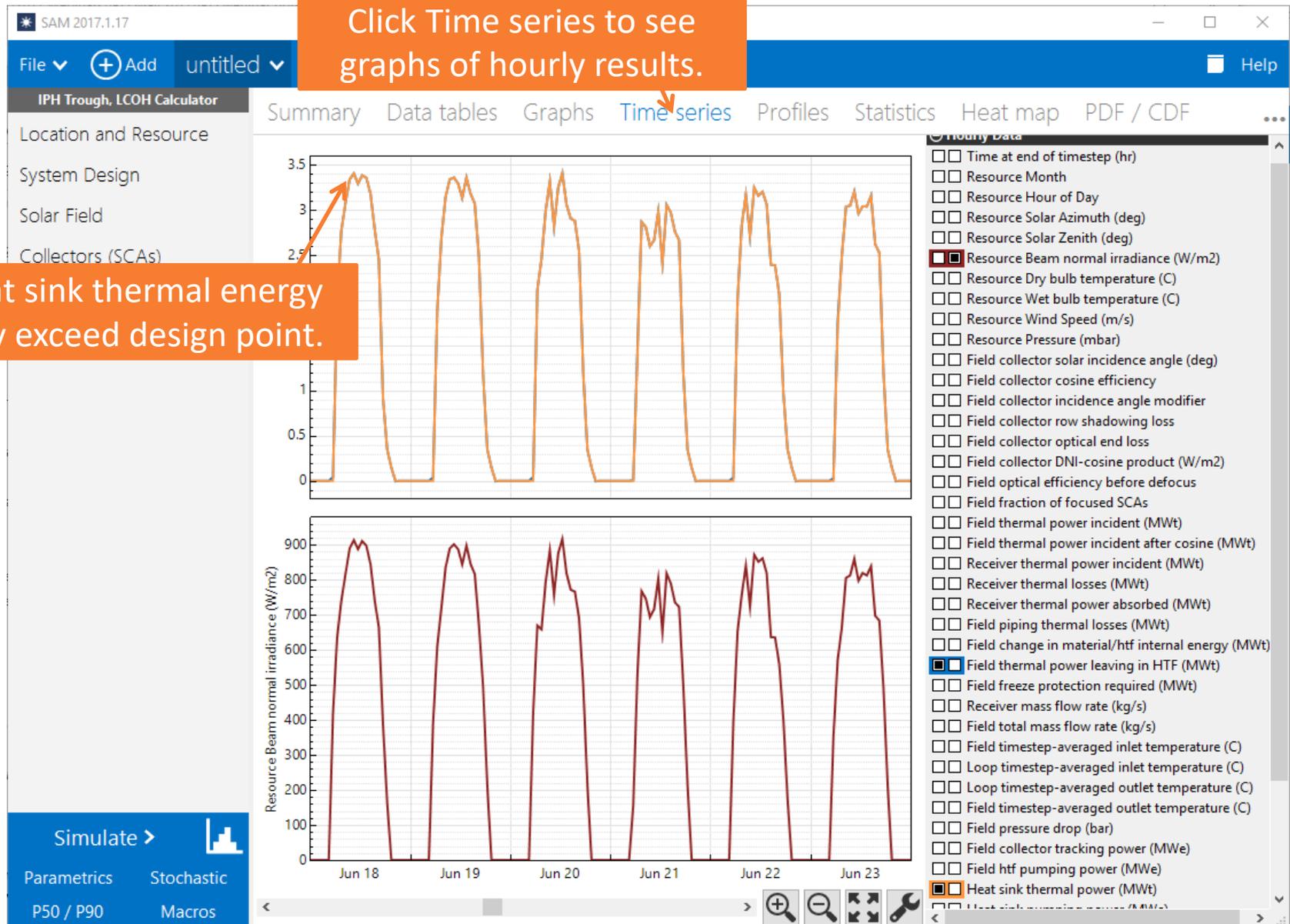
Header design min flow velocity: 2 m/s

Header design max flow velocity: 3 m/s

With no freeze protection, field thermal power is the same as heat sink thermal power

Click Time series to see graphs of hourly results.

Heat sink thermal energy may exceed design point.



IPH Trough Example: Freeze protection energy with VP-1 oil as HTF instead of pressurized water

1. Change HTF on Solar Field page
 - HTF operating temperatures change with the HTF
 - For a real analysis, you would need to change the costs to account for the different HTF
2. On the System Design page, change design loop inlet and outlet temperature to be consistent with oil HTF
3. On the Solar Field page, change the freeze protection temperature to 220 °C
4. Run a simulation, and note the differences in results
 - Field and heat sink energy are different
 - Heat loss and pumping power changes with HTF

IPH Linear Direct Steam

For IPH direct steam, you do not configure the loop

File Add Trough Linear Direct Help

IPH Linear (steam), LCOH Calculator

Location and Resource

System Design

Solar Field

Collector and Receiver

Financial Parameters

Design Point Parameters

-Solar Field-

Design point DNI 950 W/m²

Target solar multiple 1.2

Target receiver thermal power 6.00 MWt

Field inlet temperature 100 °C

Field outlet steam quality 0.75

-Heat Sink-

Heat sink power 5 MWt

Heat sink inlet pressure 20.0 bar

Heat sink fractional pressure drop 0.010

-System Availability and Curtailment-

Constant loss: 4.0 %

Hourly losses: None

Custom periods: None

Edit losses...

Steam quality is two-phase at outlet and completely condensed at inlet.

The default loss may not be appropriate for an IPH system.

Direct steam model requires knowledge of pressure drops versus size and number of modules in a loop – unlike the trough model, they are not calculated by the model. Also, no flow rate limits.

Simulate >

Parametrics Stochastic

P50 / P90 Macros

Solar field consists of a single boiler section with no superheater

The screenshot displays the SAM 2017.1.17 software interface for an IPH Linear (steam) LCOH Calculator. The interface is divided into a left sidebar and a main configuration area.

System Configuration

Design Point DNI	950 W/m ²	Field inlet temperature	100.0 °C
Target solar multiple	1.20	Heat sink inlet pressure	20.0 bar
Target receiver thermal power	6.00 MWt	Field outlet steam quality	0.75

Solar Field Design Point

Single loop aperture	3081.6 m ²	Actual number of loops	2
Loop optical efficiency	0.74613	Actual aperture	6163.2 m ²
Loop thermal efficiency	0.977567	Actual solar multiple	0.854124
Total loop conversion efficiency	0.729392	Actual field thermal output	4.27062 MWt
Total required aperture, SM=1	7215.81 m ²		
Required number of loops, SM=1	3		

Solar Field Parameters

Number of modules in boiler section	6
Solar elevation for collector nighttime stow	10 deg
Solar elevation for collector morning deploy	10 deg
Stow wind speed	20 m/s
Collector azimuth angle	0 deg
Design point ambient temperature	42 °C
Tracking power	0.20 W/m ²
Piping thermal loss coefficient	0.0035 W/K-m ² -aper

Steam Design Conditions

Freeze protection temperature	10 °C
Field pump efficiency	0.85

Mirror Washing

area of solar field	2.7 kJ/K-m ²
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Land Area

Solar field area		Total land area	1.82755 acres
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Annotations:

- An orange callout box points to the "Number of modules in boiler section" field (value: 6) with the text: "Set number of boiler modules to set the single loop aperture area."
- Another orange callout box points to the "Design point ambient temperature" field (value: 42 °C) with the text: "Design ambient temperature used in heat loss polynomials to calculate thermal efficiency at design."

Bottom Bar: Simulate > Parametrics Stochastic P50 / P90 Macros

Pressure drops not modeled physically

SAM 2017.1.17: F:\OneDrive\SAM\IPH\2017 Webinar\webinars-2017-industrial-process-heat-example.sam

File Add Trough Linear Direct Help

IPH Linear (steam), LCOH Calculator

- Location and Resource
- System Design
- Solar Field
- Collector and Receiver
- Financial Parameters

System Configuration

Design Point DNI	950 W/m ²	Field inlet temperature	100.0 °C
Target solar multiple	1.20	Heat sink inlet pressure	20.0 bar
Target receiver thermal power	6.00 MWt	Field outlet steam quality	0.75

Solar Field Design Point

Single loop aperture	3081.6 m ²	Actual number of loops	2
Loop optical efficiency	0.74613	Actual aperture	6163.2 m ²
Loop thermal efficiency	0.977567	Actual solar multiple	0.854124
Total loop conversion efficiency	0.729392	Actual field thermal output	4.27062 MWt
Total required aperture, SM=1	7215.81 m ²		
Required number of loops, SM=1	3		

Solar Field Parameters

Number of modules in boiler section	6
Solar elevation for collector nighttime stow	10 deg
Solar elevation for collector morning deploy	10 deg
Stow wind speed	20 m/s
Collector azimuth angle	0 deg
Design point ambient temperature	42 °C
Tracking power	0.20 W/m ²
Piping thermal loss coefficient	

Steam Design Conditions

Cold header pressure drop fraction	0.01
Boiler pressure drop fraction	0.075
Average design point hot header pressure drop fraction	0.025
Total solar field pressure drop	2.2 bar
Freeze protection temperature	10 °C
Field pump efficiency	0.85

Mirror Washing

Water consumption per year	12
Washes per year	12

Land Area

Solar field area	1.52296 acre	Non-solar field land area multiplier	1.2	Total land area	1.82755 acres
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Simulate > Parametrics Stochastic P50 / P90 Macros

Pressure drops are do not scale with size of loop.

BUG: Actual number of loops is not calculated correctly

The screenshot shows the SAM 2017.1.17 software interface for an IPH Linear (steam) LCOH Calculator. The 'System Configuration' and 'Solar Field Design Point' sections are visible. The 'Actual number of loops' is set to 2, which is highlighted by an orange arrow and a callout box. The 'Required number of loops, SM=1' is 3. The callout box explains that this discrepancy is a bug that will be fixed in an update at the end of May 2017.

Parameter	Value	Unit
Design Point DNI	950	W/m ²
Target solar multiple	1.20	
Target receiver thermal power	6.00	MWt
Field inlet temperature	100.0	°C
Heat sink inlet pressure	20.0	bar
Field outlet steam quality	0.75	
Single loop aperture	3081.6	m ²
Loop optical efficiency	0.74613	
Loop thermal efficiency	0.977567	
Total loop conversion efficiency	0.729392	
Total required aperture, SM=1	7215.81	m ²
Required number of loops, SM=1	3	
Actual number of loops	2	
Actual aperture	6163.2	m ²
Actual solar multiple	0.854124	
Actual field thermal output	4.27062	MWt
Drop fraction	0.01	
Drop fraction	0.075	
Drop fraction	0.025	
Pressure drop	2.2	bar
Temperature	10	°C
Loop efficiency	0.85	
Water usage per wash	0.02	L/m ² ,ap
Washes per year	12	
Thermal inertia per unit area of solar field	2.7	kJ/K-m ²
Solar field area	1.52296	acre
Non-solar field land area multiplier	1.2	
Total land area	1.82755	acres

Bug in the user interface calculation results in a field with one fewer loop than indicated here. For IPH systems with small fields, this can significantly decrease the solar multiple. WILL BE FIXED IN UPDATE AT END OF MAY 2017

Boiler section is a generic optical model, and requires that you characterize the field optical efficiency outside of SAM

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File Add Trough Linear Direct Help

IPH Linear (steam), LCOH Calculator

- Location and Resource
- System Design
- Solar Field
- Collector and Receiver
- Financial Parameters

Boiler Geometry and Optical Performance

Reflective aperture area: 513.6 m²

Length of collector module: 44.8 m

Tracking error: 1

Geometry effects: 0.84

Mirror reflectivity: 0.935

Mirror soiling: 0.95

General optical error: 1

Optical characterization method:

- Solar position table
- Collector incidence angle table
- Incidence angle modifiers

-Solar Position/Collector Incidence Angle Table-

Import... Export... Copy Paste Rows (zenith): 11 Cols (azimuth): 20

	-180	-160	-140	-120	-100	-80	-60	-40
0	1	1	1	1	1	1	1	1
10	0.98	0.974445	0.971976	0.972847	0.97691	0.97691	0.972847	0.971976
20	0.93	0.922976	0.92893	0.946005	0.954019	0.954019	0.946005	0.92893
30	0.84	0.838618	0.870691	0.913021	0.940911	0.940911	0.913021	0.870691
40	0.72	0.729947	0.803687	0.866961	0.900039	0.900039	0.866961	0.803687
50	0.55	0.591255	0.707454	0.793509	0.83956	0.83956	0.793509	0.707454
60	0.34	0.432178	0.597478	0.664006	0.693511	0.693511	0.664006	0.597478
70	0.13	0.265254	0.425586	0.464496	0.477106	0.477106	0.464496	0.425586
80	0.01	0.113694	0.20891	0.233255	0.238828	0.238828	0.233255	0.20891

Specifying solar position table: Rows indicate solar zenith angles (deg)

Specifying collector incidence angle table: Rows indicate long angles (deg)

-Incidence Angle Modifier Coefficients-

	Const	C1	C2	C3	C4
Transverse incidence angle modifier	0.9896	0.044	-0.0721	-0.2327	0
Longitudinal incidence angle modifier	1.0031	-0.2259	0.5368	-1.6434	0.7222

Receiver Geometry and Heat Loss

Polynomial heat loss model

-Polynomial fit heat loss model-

	C0 (W/m)	C1 (W/m-K)	C2 (W/m-K ²)	C3 (W/m-K ³)	C4 (W/m-K ⁴)
Steam temperature adjustment	0	0.672	0.002556	0	0

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Optical efficiency tables or IAM coefficients are available in the research literature.

Receiver parameters

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File Add Trough Linear Direct Help

IPH Linear (steam), LCOH Calculator

Location and Resource
System Design
Solar Field
Collector and Receiver
Financial Parameters

Receiver Geometry and Heat Loss

Polynomial heat loss model

-Polynomial fit heat loss model-

	C0 (W/m)	C1 (W/m-K)	C2 (W/m-K ²)	C3 (W/m-K ³)	C4 (W/m-K ⁴)
Steam temperature adjustment	0	0.672	0.002556	0	0
	C0	C1 (1/(m/s))	C2 (1/(m/s) ²)	C3 (1/(m/s) ³)	C4 (1/(m/s) ⁴)
Wind velocity adjustment	1	0	0	0	0

-Evacuated tube heat loss model-

Absorber tube inner diameter	0.066 m	Absorber flow plug diameter	0 m
Absorber tube outer diameter	0.07 m	Internal surface roughness	4.5e-005
Glass envelope inner diameter	0.115 m	Absorber flow pattern	Tube flow
Glass envelope outer diameter	0.12 m	Absorber material type	304L

	Variation 1	Variation 2	Variation 3	Variation 4*
Variation weighting factor	0.985	0.01	0.005	0
	0.96	0.96	0.8	0
	0.1384	Value Table 0.65	Value Table 0.65	Value Table 0.1384
	0.02	0.02	0	0
Envelope emittance	0.86	0.86	1	0
Envelope transmittance	0.963	0.963	1	0
<input type="checkbox"/> Broken Glass		<input type="checkbox"/> Broken Glass	<input checked="" type="checkbox"/> Broken Glass	<input type="checkbox"/> Broken Glass
Annulus gas type	Air	Air	Air	Air
Annulus pressure (torr)	0.0001	750	750	0
Estimated avg. heat loss (W/m)	150	1100	1500	0
Bellows shadowing	0.96	0.96	0.96	0
Dirt on receiver	0.98	0.98	1	0

Aggregate Weighted Losses

Average field temp difference at design	204.5 °C
Heat loss at design	244.317 W/m
Receiver thermal derate	0.977567
Receiver optical derate	1
Collector optical loss at normal incidence	0.74613

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Specify polynomial coefficients or use physical model of evacuated tube.

- If you have questions after the webinar or are watching a video recording, please contact us with questions:
 - <https://sam.nrel.gov/support>
 - sam.support@nrel.gov

Thank you!

www.nrel.gov

